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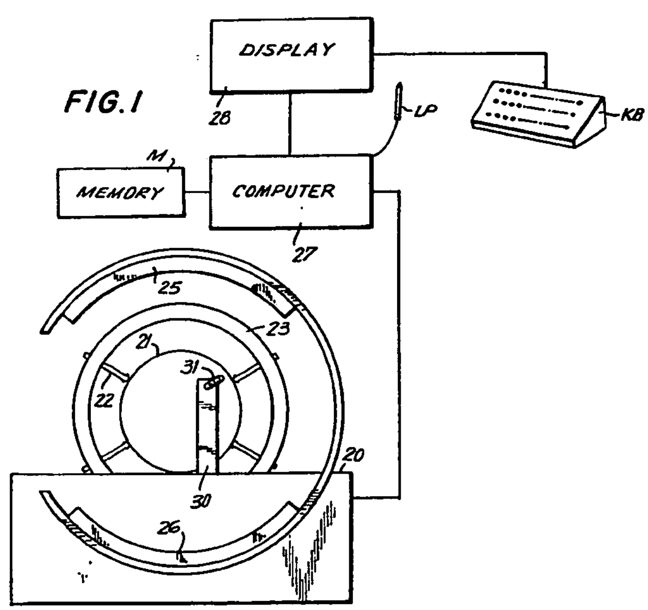
(54) Apparatus for stereotactic surgery

(57) A stereotactic surgery apparatus has a probe (31) and a computerized tomographic scanning system. The scanning system comprises a display (28), and means for reconstructing cross-sectional images on said display using data from partial circumferential scans of source (25) and detectors (26) and operating on the data with an algorithm that provides the difference between the local values of the linear attenuation coefficient and average of these values within a circle centered at each reconstruction point. The scanning system includes means maintaining the frames of reference of said probe means and scanning system rigid with respect to one another. The position of the probe, which may be a cryogenic probe, with respect to the actual anatomical structure of the body, particularly a human head (21), may thus be viewed by the surgeon.

FIG. 1



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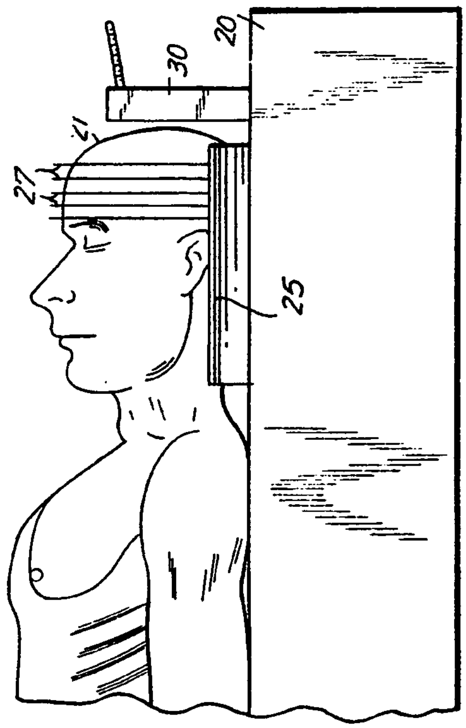


FIG. 2

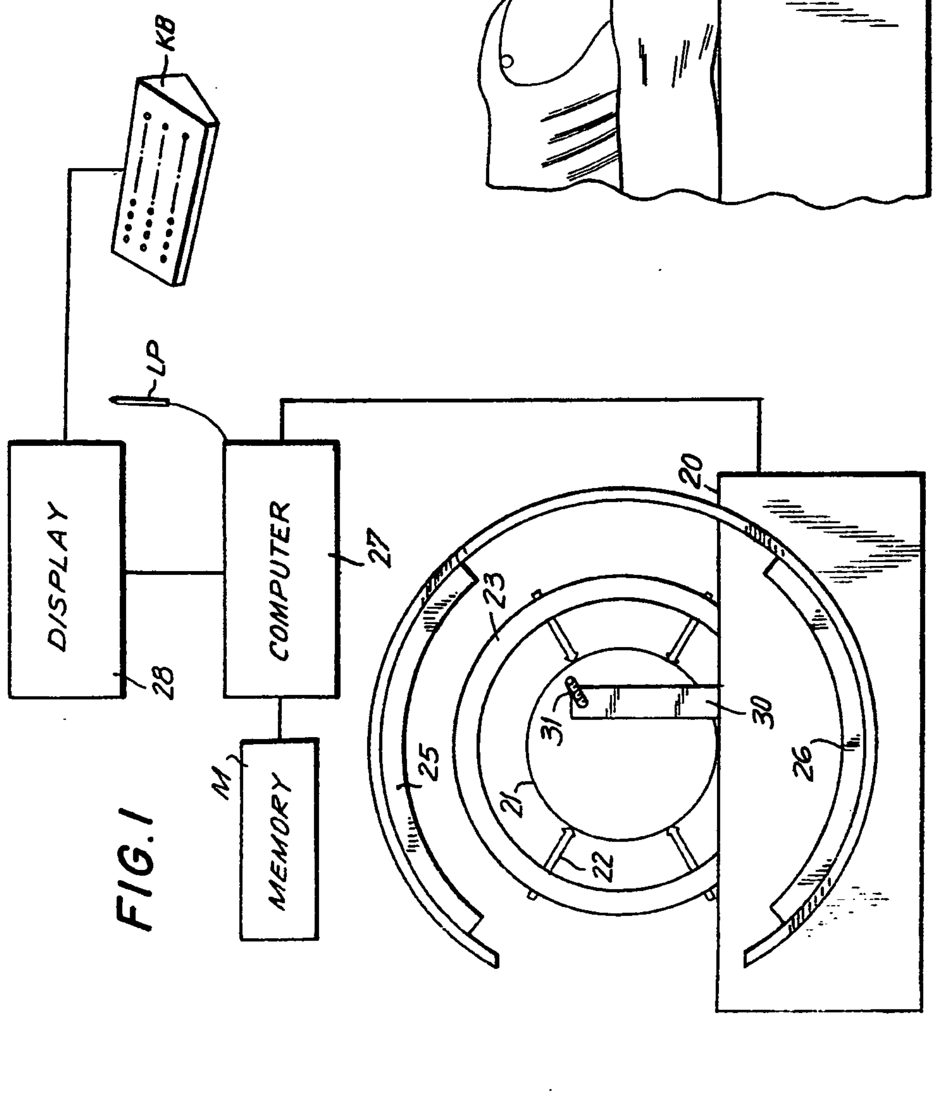
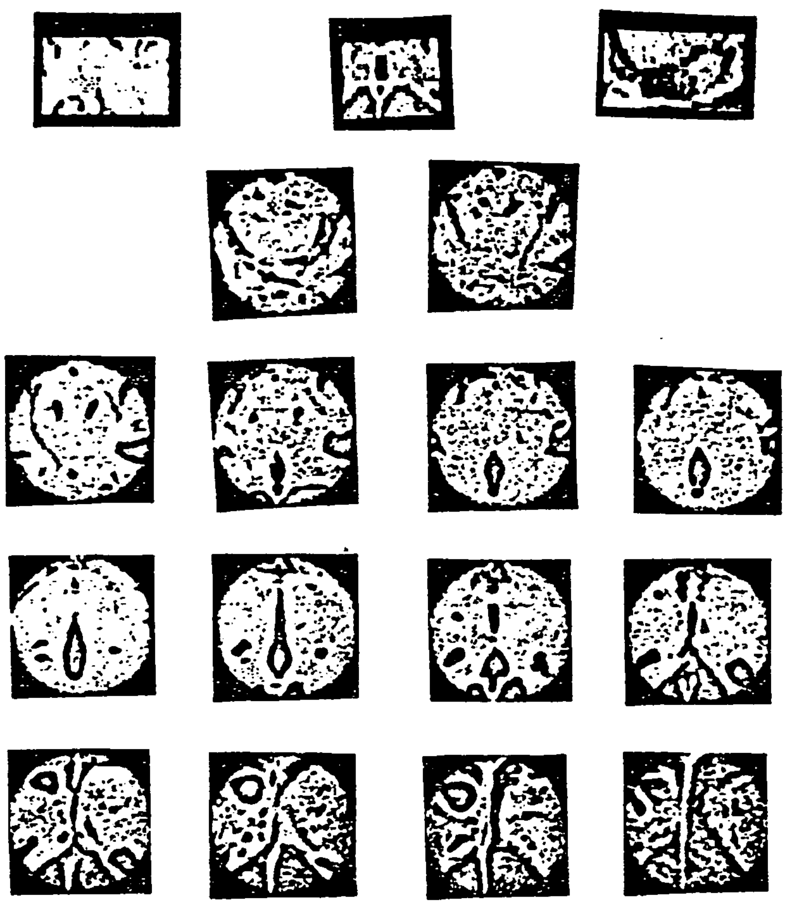


FIG. 1

FIG. 3



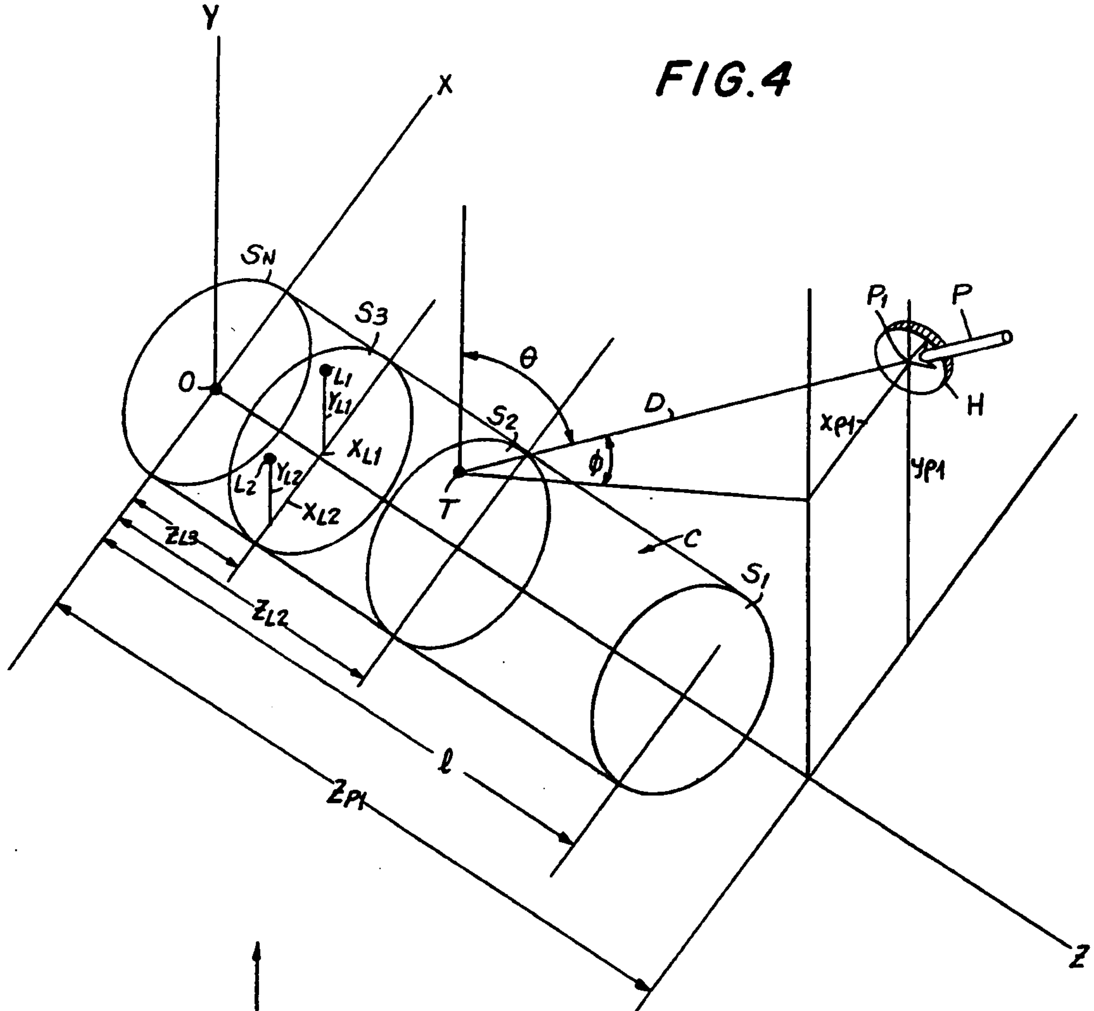

Y
X
SN
S3
O
L1
YL1
XL1
L2
YL2
XL2
θ
S2
D
ϕ
T
P1
P
H
XP1
YP1
C
S1
ZL3
ZL2
ℓ
ZP1
Z

FIG.4

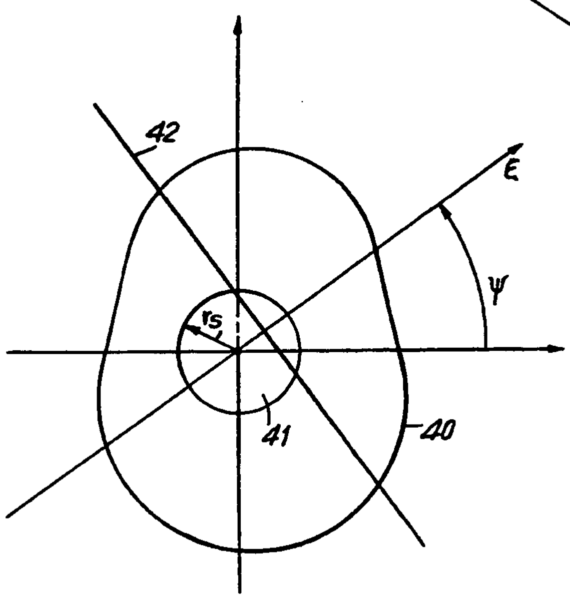

42
ε
ψ
rS
41
40

FIG.5

FIG.6

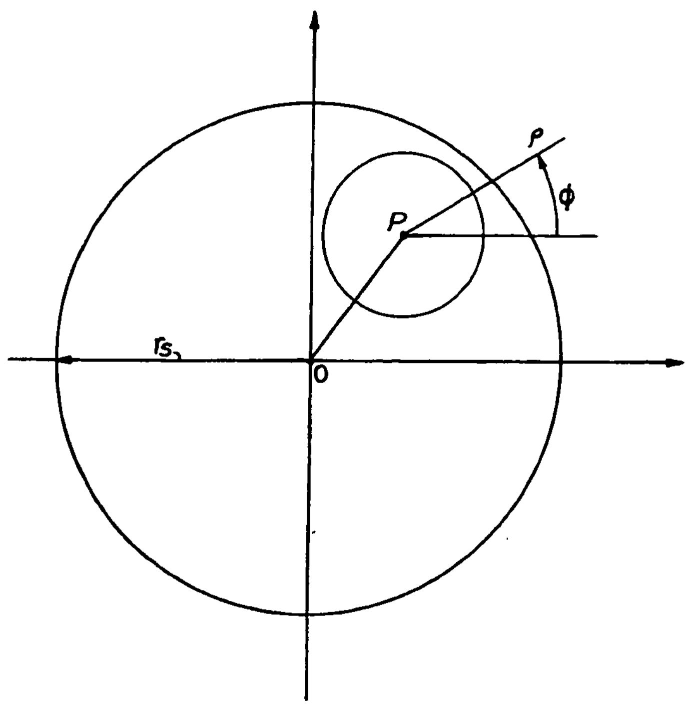


FIG.7

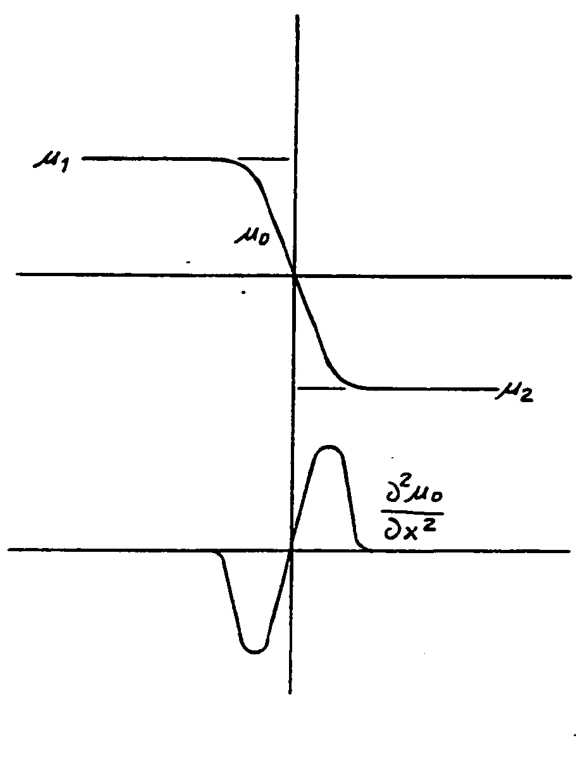


FIG.9

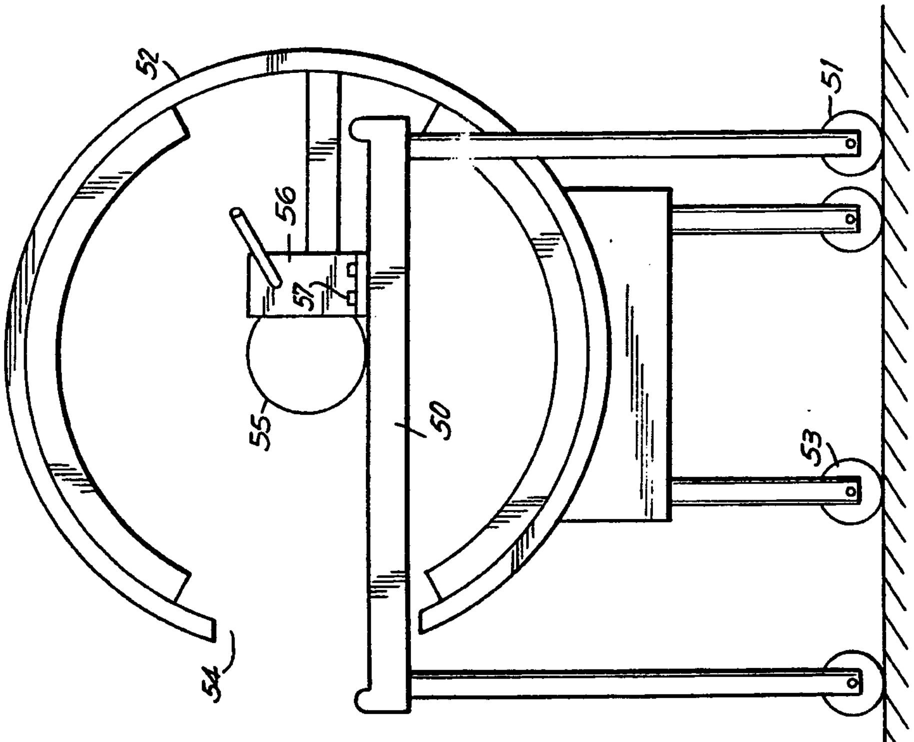


FIG.8

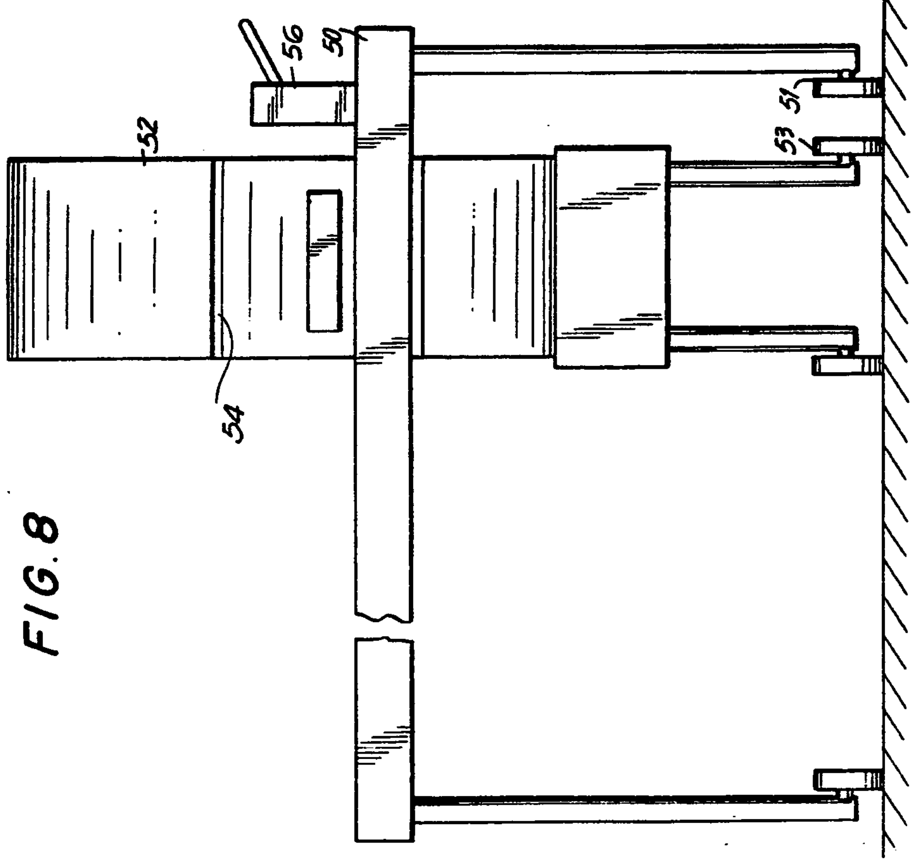


FIG. 10

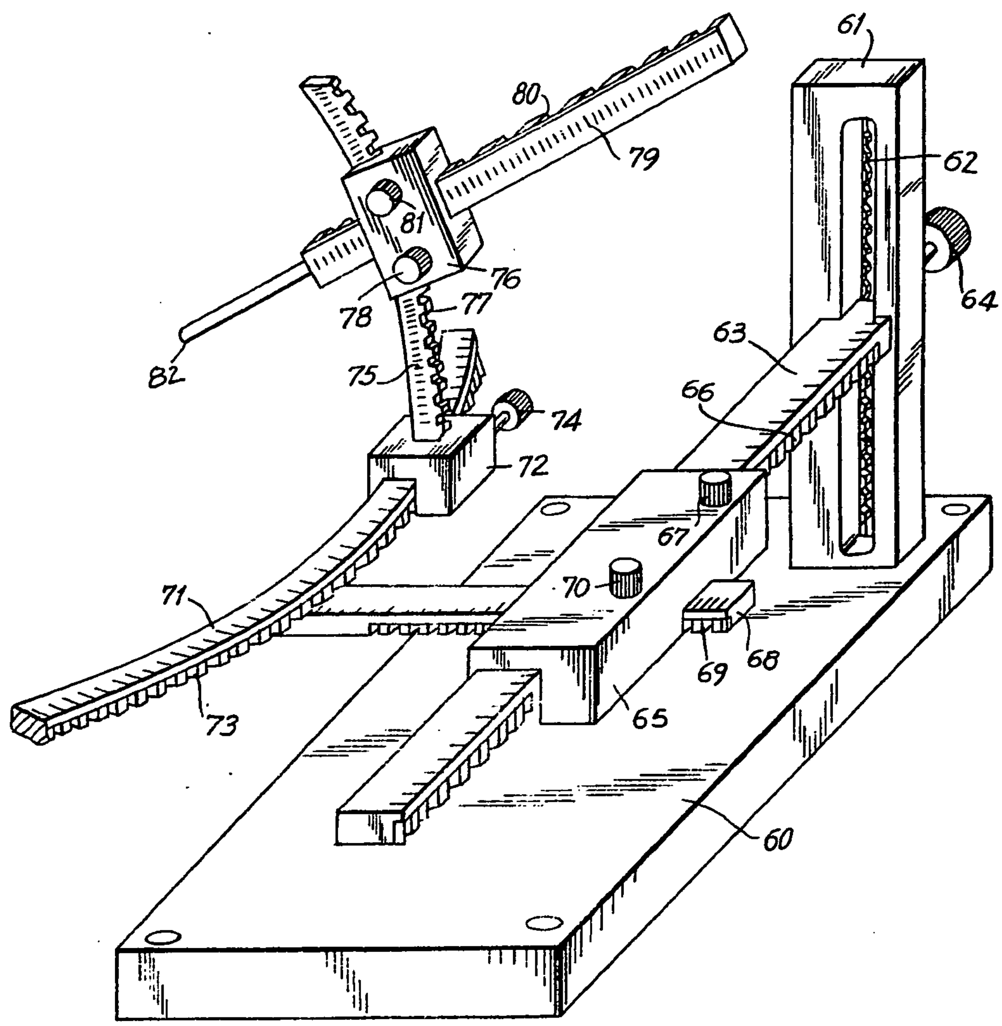


FIG. 11

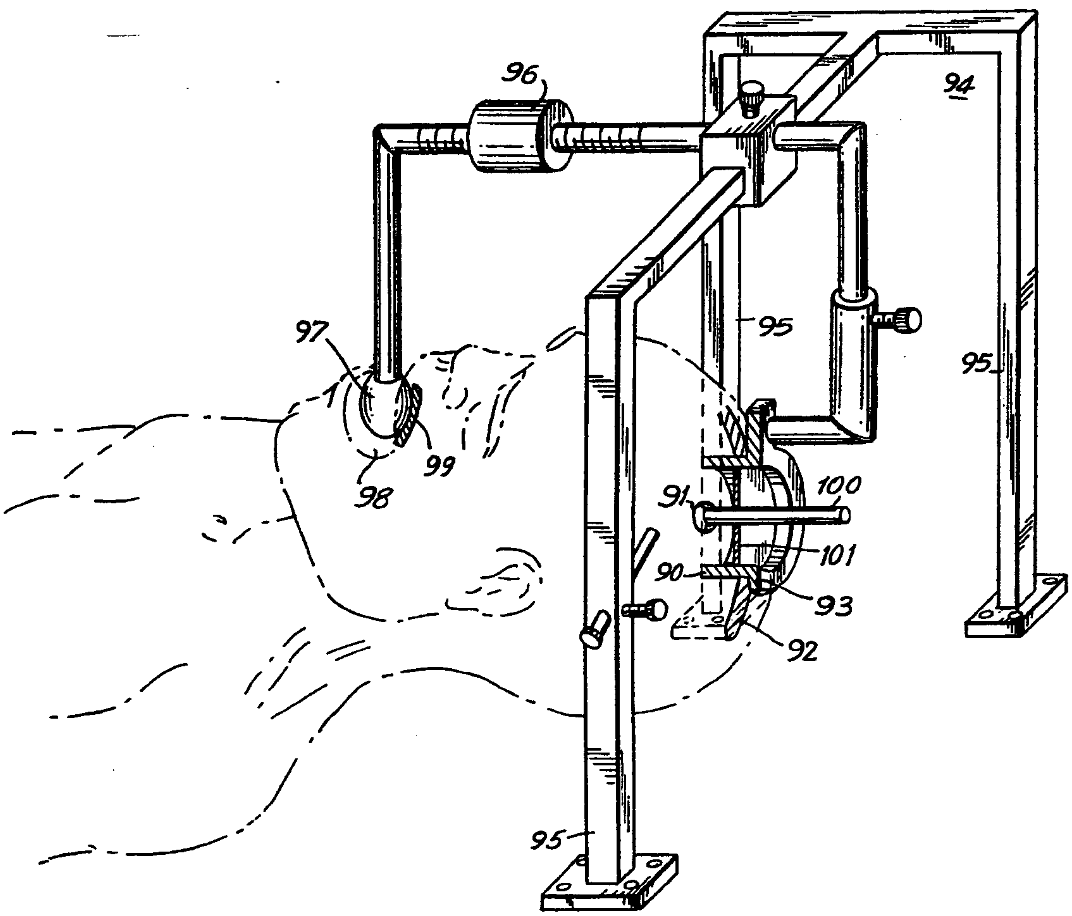
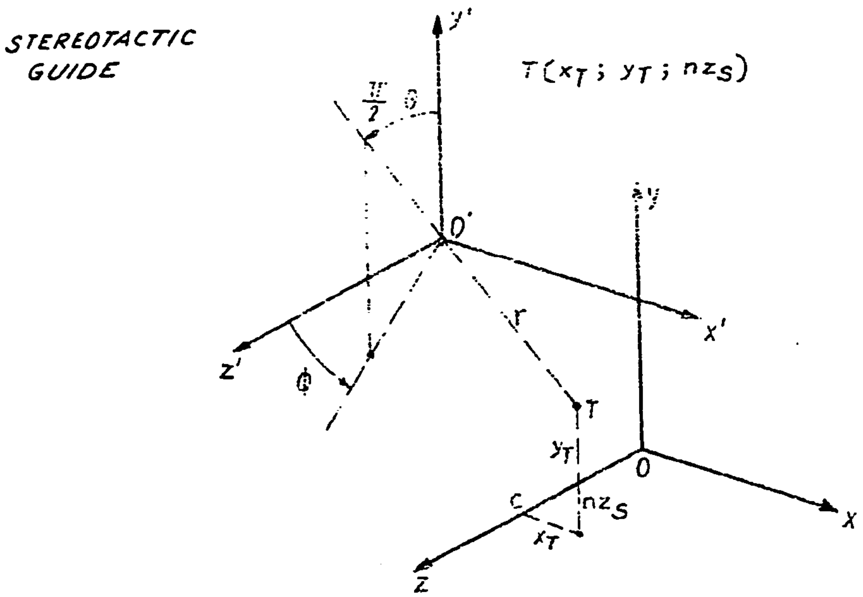


FIG. 12



x', y', z' - THE FRAME OF REFERENCE OF THE STEREOTACTIC GUIDE SYSTEM, WITH THE ORIGIN O' AT THE CENTER OF ROTATION OF THE PROBE. AXES x', y', z' ARE PARALLEL TO AXES x, y, z RESPECTIVELY.

x, y, z - THE FIXED FRAME OF REFERENCE OF THE SCANNER. THE PLANE x, y IS THE SCANNING PLANE, WITH THE ORIGIN O AT THE CENTER OF ROTATION OF THE SCANNER.

x - HORIZONTAL AXIS POINTING TO THE SURGEON'S RIGHT.

y - VERTICAL AXIS POINTING UP

z - AXIS PERPENDICULAR TO THE SCANNING PLANE, POINTING TOWARD THE SURGEON.

r, θ, ϕ - THE SPHERICAL FRAME OF REFERENCE, WITH THE ORIGIN AT O'.

r - PENETRATION OF THE PROBE

θ - ANGLE WITH RESPECT TO THE HORIZONTAL PLANE. A POSITIVE VALUE OF θ CORRESPONDS TO THE PROBE POINTING DOWN.

ϕ - ANGLE FORMED BY THE VERTICAL ARC OF THE GUIDE SYSTEM WITH RESPECT TO THE y', z' PLANE. A POSITIVE VALUE OF ϕ CORRESPONDS TO AN ANTI-CLOCKWISE ROTATION ABOUT y'.

z_S - THE INCREMENTAL STEP OF THE SCANNING PLANE USED IN THE SCANNING SEQUENCE.

SPECIFICATION

Apparatus for stereotactic surgery

This invention relates to a method and apparatus for stereotactic surgery, and is more particurarly directed to a method and apparatus for employing computerized tomography in surgical operations. While the invention will be disclosed with particular reference to the requirements of brain surgery, it will be apparent that the invention may advantageously be employed for other procedures.

Stereotactic surgery is a sub-specialty of neurosurgery and defines a class of operations in which probes, such as cannulae, needles, forceps or electrodes are placed into brain regions or anatomical targets that are not visible on the surface of the brain. The general location of these regions is determined by measurements from landmarks visualized by x-ray or other means, such measurements being based on atlases derived from anatomical studies and autopsy. Because of anatomical variability, more precise location in any single patient may be determined by physiological responses in that patient. The degree of success in stereotactic surgery depends upon the experience of the surgeon as well as the precision of the stereotatic instrument and radiologic brain imaging technique.

A stereotactic instrument is a guiding device used in human neurosurgery for the purpose of directing an instrument to a specific point within the brain by radiographic or other visualization of landmarks, through a small opening in the skull. Stereotactic instruments are constructed to afford the surgeon reliably reproducible accuracy in placing instruments into target areas. Proper positioning of the probe is often verified by x-rays to control errors in calculation and to correct deflection of the probe during insertion. Physiologic parameters may be used to further define the optimal target.

At the present time, stereotactic instruments are used most frequently, but not exclusively, in the following operations.

Thalamotomy for parkinsonism and other types of tremor,

Electrode implantation for epilepsy,

Needle and/or magnet insertion for aneurysm thrombosis,

Thalamic or subthalamic operations for involuntary movements such as chorea or hemiballismus,

Ablation of deep cerebellar nuclei for spasticity,

Cingulotomy and thalamic or subthalamic surgery for pain,

Mesencephalotomy for pain,

Ablations for subcortical temporal lobe structures for treatment of epilepsy,

Psychosurgical procedures,

Implantation of depth stimulating electrodes for pain,

Insertion of forceps or needle for obtaining biopsy specimens,

Foreign body removal, and

Implantation of radioactive material

Biopsy or treatment of tumors

The list is presented only to give examples for some applications. It is not required to hit a point in space, but to hit a volume or make a lesion within a mass. The purpose of stereotactic apparatus is to guide the advance of an electrode or other probe accurately and in a controlled fashion to a given point in space, relative to the apparatus, the stereotactic target. Thus, when the apparatus is attached to the skull, the probe can be advanced to a given geographical point within the cranial cavity, near the base of the skull, or in the spinal canal. As generally employed, the ventricles or cavities within the brain or other cerebral landmarks are identified roentgenographically or by other means and, by consulting an atlas or other table, the mean distance and direction between the visualized landmark and a given anatomical target are measured. The probe is then inserted to the stereotactic target, that is, the point in space within the cranial cavity which is calculated from the distance and direction between the visualized landmark and the desired target in relation to the coordinate system of the stereotactic apparatus. It is recognized that there is considerable anatomical variability in brain size and shape so that the target point is identified from the atlas or table is only approximate. Usually, where possible, physiological verification may also be obtained. One must distinguish between the anatomical accuracy, which is inexact because of the variability of brains, and the mechanical accuracy, which is a function of the precision of the stereotactic instrument.

In the utilization of computed tomography for stereotactic surgery some targets may be directly visualized in an image, such as a brain tumor.

As previously stated x-ray images of the brain are currently used in neurosurgery to locate the pertinent landmarks. In principle a series of images in orthogonal planes allows the neurosurgeon to determine landmark coordinates. Unfortunately a landmark may not be readily identifiable because of the poor density resolution of conventional x-ray images and uncertainties about the head orientation.

Computerized tomography provides a new imaging technique which not only has high density resolution capabilities, but also provides a quantitative information about the anatomy. In accordance with the invention, computerized tomography can be integrated in a neurosurgical procedure to provide major improvement in target identification.

Basic concepts of CT scanning and the displays related thereto are described in U.S. Patent No: 3,778,614, issued December 1, 1973, the disclosure of which is specifically incorporated herein by reference.

A comprehensive analysis of the integration of computerized tomography CT in neurosurgery requires a definition of the differences between surgical requirements and the scanning configuration and data presentation in commercial CT scanners which are designed to satisfy diagnostic requirements.

The basic information obtained from a conventional CT image is the value of local tissue density which is used for diagnosis of tissue anomalies. The spatial density distribution generates the information about the anatomy and the location and dimen-

sions of tissue anomalies. Thus for diagnostic purposes, spatial resolution in the image plane, as well as thickness of the tissue "slice" covered in each scanning, are selected to achieve a maximum sensitivity in tissue density discrimination. This contrasts with the requirements of a surgical procedure, where the anatomy and in particular the outline of body organs is the dominant parameter to determine either target point or landmark location. Scanning parameters and image reconstruction algorithm must then be selected to obtain a maximum precision in target location measurement while tissue density discrimination may become of secondary importance.

In a normal CT scanner procedure for diagnostic purposes a multiplicity of scans may be taken to explore the entire region of the brain as well as to determine the three dimensional properties of the tissue element under scrutiny. The distance betewen scanning planes or slices and the thickness and number of slices depend upon the specific information which is sought by the clinician in each particular case. In a surgical procedure the sequence of scans must provide the spatial coordinates of a target point. Thus, in a general case, the element of volume of interset must be explored uniformly with a sequence of scans at intervals selected to maintain a uniform spatial resolution throughout the element of volume.

With respect to the dimensions of the volume to be scanned, for diagnostic purposes a series of total scans of the head are necessary, while in a surgical procedure the scans may be limited to the region of interest, because by the time the patient is brought into the surgical room, the diagnosis has been completed and conventional scan results are available to the surgeon. Dimensions of the order of 5 cm. of the volume to be imaged during the surgical procedure are adequate for the brain. The surgical scanner can then be designed for partial scanning with two important advantages. First the limited extent of the partial scanning region makes it possible to achieve a high spatial resolution without increasing the total x-ray dose. Second size and weight of the gantry of a scanner designed for partial scanning in such a small region may be drastically reduced compared to a conventional scanner.

The above considerations refer primarily to the imaging logic and scanning modality. Additional important considerations have to be made regarding surgical instrumentation and procedure as well as patient handling. First of all, the stereotactic guide and the head support must be designed to minimize their interference with the x-ray beam throughout the scanning sequence. The design of the stereotactic guide can easily be arranged to keep the controls and supports outside of the scanning planes. On the other hand conventional head holders are not so easily adapted to this system because of the relatively small degree of freedom in the location of constraining pins which hold the skull in the proper position. If the pin structure must cross the scanning plane, considerable care has to be taken in the selection of materials and in the design of the support to avoid the creation of strong artifacts throughout the image. However, the design of these surgical components is only a part of the total problem of satisfying both surgical and scanning requirements. It is well known that the image reconstruction requires the acquisition of data over a rotation of the x-ray source of at least 180° in the scanning plane. This has resulted in a closed configuration of all commercial scanners with an opening whose dimensions are dictated by the cross section of the human body. The closed configuration and the position of the scanning plane relative to the patient support makes a commercial scanner hardly suitable for stereotactic surgical procedures since it interferes with the surgeon's access to the surgical area. Thus size and shape of the scanner gantry are thus an important factor in the design of an integrated surgical system.

In addition, patient handling procedures for diagnostic purposes may not be suitable for surgical applications. In a commercial scanner, with the exception of gantry tilting, it is the patient support that undergoes axial as well as vertical motion to position a given section of the patient body in the scanning plane. In a surgical procedure a preliminary phase involves arrangement of the patient in a position which satisfies both the surgical and scanning requirement. This phase may involve the control of position and orientation of both scanner gantry and patient support. However, once the preliminary phase is over and the patient's head is locked in its support, the ideal situation is to keep the patient immobile and to confine all motions to the instrumentation including the indexing of scanning positions during the scanning sequence.

In accordance with the invention, the image reconstruction algorithm and the orientation of the image planes are selected to optimize primarily the presentation of tissue anatomy rather than tissue characteristics. In addition, the scanning procedure is limited to a partial scanning of the volume of interest with a spatial resolution uniform in the scanning plane as well as perpendicular to the scanning plane. A low scanning speed to optimize image quality must be selected as a trade-off between x-ray dose within the region of partial scanning and total scanning time of the volume of interest. The dimensions of the volume explored in the partial scanning procedure is selected as a trade-off between surgical requirements and amount of data and computational time. Head holder and stereotactic guide are preferably designed to minimize their interference with the scanning procedure throughout the volume of interest. The gantry is designed to minimize obstructions to the surgeon's access to the surgical area and provide maximum flexibility in patient positioning. Translations and angular orientations required by the scanning procedure are implemented in the scanner gantry rather than in the patient support. In a preferred embodiment of the invention, safety features are built into the scanner for possible emergencies, including the rapid removal of the gantry from the patient support should the need arise.

Additional features are preferably included to monitor the actual surgical procedure. Upon completion of the target identification phase and adjustment of the orientation controls of the stereotactic

guide, the probe is driven into the brain to reach the depth of the target point. The penetration has to be monitored by measuring the coordinates of the probe tip position prior to reaching the target point. Thus the x-ray system of the scanner is used to monitor the probe tip position at prescribed points of the probe trajectory.

In order that the invention will be more clearly understood, it will now be disclosed in greater detail with reference to the accompanying drawings, wherein:

Fig. 1 is a simplified illustration of the end view of one embodiment of an apparatus in accordance with the invention;

Fig. 2 is a simplified illustration of a side view of a portion of the arrangement of Fig. 1;

Fig. 3 is a view of a display, such as on a cathode ray tube, in accordance with the invention;

Fig. 4 is an illustration explaining the principle of operation of the invention;

Fig. 5 is a further illustration regarding the geometric configuration employed in conjunction with the invention;

Fig. 6 is a schematic illustration of the geometric parameters concerned with the partial scanning aspect of the present invention;

Fig. 7 illustrated a distribution in the proximity of the interface between regions of different values;

Fig. 8 is a side cross-sectional view of an operating table illustrating placement of the present invention;

Fig. 9 is an end view of the arrangement shown in Fig. 8;

Fig. 10 is a detailed illustration of the probe assembly;

Fig. 11 is an embodiment of a holding mechanism assuring rigidy of the patient with respect to the probe assembly;

Fig. 12 is a geometric presentation illustrating mathematically the relationship between the rigidly coupled sets of coordinates employed in conjunction with the present invention.

Referring now to the drawings and more in particular to figure 1, therein is illustrated in simple form an apparatus in accordance with the invention. This figure depicts a table 20 upon which a patient is lying, the top of the head of the patient being depicted by circle 21. The patients head must be rigidly held in position on the table, and for this purpose a plurality of bars 22 may be provided extending radially inwardly from a supporting frame 23, the bars 22 or the like rigidly engaging the skull of the patient. Of course this method of holding the patients head is exemplarly only, and any other conventional way of rigidly holding the head may be alternatively employed.

The table is provided with scanning means for providing partial scanning, in accordance with U.S. Patent Application Serial No. 635,165, filed November 25, 1975. This partial scanning apparatus is employed with an open configuration, since, by its use it is not necessary to encircle the head of the patient with a scanning apparatus, thereby enabling the surgeon to have more freedom of movement above the patient's head. The scanning apparatus is depicted by a source of radiation 25 and a series of detectors indicated by the reference numeral 26. The source 25 may be a penetrating source, such as x-rays, providing a fan shaped beam movable in a given arc, and the detectors 26 may be comprised of a plurality of detectors for receiving such radiation, and providing an output to a computer 27 such as a PDP 11/35 of Digital Equipment Corporation, New York, N.Y. The arrangement of the source 25 and detector 26 enables a scan of a circle of given radius, for example, at a determined position within the brain of the patient.

It is important to note that the reconstruction of images is effective in accordance with an algorithm herein referred to as a delta μ aglorithm. This algorithm, which will be discussed in greater detail in the following paragraphs, enables a sharp definition of regions of the brain, thereby permitting the use of apparatus of this type in accordance with the present invention. The computer may be coupled to a display device 28, for displaying reconstructed images, as will be further discussed. Also included is a memory M for data corresponding to prestored locations of specific features related to areas under scan. A keyboard KB is provided for entering data into the computer, and a light pen LP is provided for allowing the operator to locate and enter data directly from the display.

Figure 2 depicts a end view of the apparatus of figure 1, wherein it is seen that the source 25, and hence also the detector 26, are movable in a locus extending axially of the table, i.e., from the head to the feet of the patient. Figure 2 also illustrates a plurality of vertical lines 27 substantially equally spaced apart in the region of the brain of the patient. These lines 27 depict scanning planes which may be, for example, 2.5 millimeters apart. The scanning apparatus comprised of the source 25 and detector 26 is thereby movable in the axial direction, to enable discrete scanning of the various planes 27.

Figure 3 is an illustration of a pattern that may be provided on the display device 28, in accordance with a typical operation of the apparatus. This illustration shows 14 images, in the top four rows, which are reconstructed images in different vertical planes through the brain of the patient. The three lower images in figure 3 are reconstructed transverse images, i.e., images reconstructed from the data taken in all of the slices to reconstruct images in planes extending axially i.e. from head to foot, of the patient. The form of reconstruction of such images, and the algorithms thereof are not the subject of this invention, although a somewhat more complete explanation thereof will be given in the following paragraphs.

Referring again to figures 1 and 2, a movable support 30 is illustrated adjacent the top of the skull of the patient, and probe 31 is supported by the support 30.

The support 30 enables the positioning of the tip of the probe at any given location adjacent the skull, and provides means for indicating the coordinates of the tip of the probe with respect to the frame of reference of the scanning mechanism i.e. the source of radiation 25 and a detector system 26. The coordinate system may, for example, have an X-coordinate

extending horizontally relative to the top of the table and transversely thereof, a Y-coordinate extending vertically, and a Z-coordinate extending perpendicular to the scanning plane, for example, through the center of the scan region of the scanner. In other words, the support for the probe enables the location of the probe precisely with respect to the scanning system. The probe itself is also adjustable in 3 different senses. In the first sense, the angle of the probe may be adjusted precisely with respect to the plane of the table, i.e., the horizontal plane. Further, the angle of a vertical flow containing the probe with respect to a vertical axial plane, i.e., a plane defined by the Y and the Z coordinates may also be precisely set. Further, the length of the probe extending from the point of reference along the given angles may also be precisely determined.

At this point it will noted that the probe may be any conventional probe such as, for example only, a cryogenic probe.

The principal of operation of the system in accordance with the invention will be more clearly understood by reference to figure 4, which illustrates geometrically the parameters of the invention.

When a partial scan is made, as above discussed, complete data is obtained in a circular area having a small radius. When a series of scans is made at spaced apart axial positions, a plurality of slices S_1 to S_N will be made in a scan thereby defining a cylindrical region C within which all scans occur. The length 1 of the cylinder is of course determined by the number of slices and the distance between each slice. In the scan illustrated in figure 3 for example 14 such slices are shown, although a greater or lesser member of such slices may be taken as desired. The position of each slice in the Z direction from the center O of the coordinate system is precisely defined by the geometry of the system, and this data is directed to the computer, so that the computer may precisely identify the axial position of each slice.

In one mode of operation of the system of the invention a plurality of slices of the brain are scanned to provide a display such as illustrated in figure 3. The surgeon upon study of slices reconstructed on the screen of the display device, may determine that a particular point in a specific slice is of interest. In accordance with conventional practice, any of the slices may be enlarged on the screen for closer inspection. Assume, for example, that the display slice corresponding to the slice S_2 of figure 4 is of interest to the surgeon, and that the point T of this slice is the point to which it is desired to insert a probe. Upon inspection of the corresponding reconstruction on the screen, the surgeon may direct a light pen to this spot thereby identifying the spot to the computer. The computer thereby obtains precise information of the true coordinates of this point T.

In addition, due to the rigid mechanical coupling between the frame of reference of the scanning system and the frame of reference of the probe P of figure 4, the data corresponding to the coordinate positions of the tip P_1 of the probe may be either manually or automatically directed to the computer. These coordinates may be, for example, X_{P1}, Y_{P1}, and Z_{P1}. With this data, the computer may readily calculate the angle θ of the line D to the horizontal, the angle ϕ of the line D to the vertical axial plane, and the distance between the point T and the point P_1. With this information, which may be displayed on the display device, the probe may be manually or automatically directed in the proper direction to the point T, and inserted for the exact distance to reach this point. In figure 4, the point P_1 is illustrated at the center of a circle H, this circle representing the hole that must be drilled in this hole for insertion of the probe T. The point T_1 of the initial position of the tip of the probe is preferably defined at the center of this hole, which may be drilled either before or after the scanning resulting in the display of figure 3.

In a further embodiment of the invention referring again to Fig. 4, a slice S_3 is illustrated as having two points L_1, L_2. These points have the coordinate positions X_{L1}, Y_{L1}, Z_3 and X_{L2}, Y_{L2} and Z_{L3} respectively. These points L_1 and L_2 represent landmarks in the brain, and are shown in the same slice for exemplary purposes only. For example, the landmarks may be the anterior commissure, and the posterior commissure. Due to the use of the delta μ algorithm, such landmarks may be readily located by view of a display, and their coordinate positions may be reaidly identified. For example, by employing a light pen and identifying a specific landmark in an input to the computer, as by a keyboard selection or light pen activated displayed list the computer may identify data corresponding to each of the landmarks. The "Atlas for Stereotaxy of the Human Brain", Schaltenbrand and Wahren, second edition George Thieme, publisher, 1977, provides standard references relative to the line between the anterior commissure and the posterior commissure, so that the positions of the specific points in the brain relative to such line may be precisely located, in direction and distance. The data of this Atlas may be provided in the memory of the computer, so that, upon entry of the coordinate positions of the anterior and posterior commissures, and the entry of a code corresponding to another specific location in the brain, the computer may readily calculate the coordinate positions of such other point.

In other words, in accordance with the invention, the partial scans, employing the delta μ algorithm, may be employed to locate and identify the anterior and posterior commissures, thereby to enable positioning of the probe at another specific point in the brain without a requirement that such other point be positively identified in the planes displayed on the CRT. This procedure is possible due to the rigid mechanical coupling of the frames of reference of the scanning system and the probe support system, as well as to the definition of the reconstructive images resulted from the use of the delta μ algorithm.

The method and apparatus in accordance with the present invention is consequently not limited to diagnostic applications, but, to the contrary, enables the use of operation devices in combination with scanning devices, thereby enhancing the usefulness of each. By incorporating the partial scanning system with the probe system and rigidly coupling the

frames of references of these two devices information regarding the positioning of the probe is substantially instantly available or as soon as required by the surgeon. The partial scan system further frees a substantial space about the head of the patient as contrasted to complete scan systems, thereby simplifying surgical procedures. Due to the use of the delta μ algorithm, specific landmarks or other areas of interest in the brain can be positively identified with sufficient accuracy that the rigid coupling of the frames of references has a significant value in the positioning of the probe. The accuracy provided by the method and apparatus hence is sufficient to ensure the correct positioning of the probe at the desired location, without the necessity for transporting a patient between an operating area for example, an x-ray area, to ensure that the position of the probe has the desired effects.

With respect to the accuracy of location of the slices in the axial or the Z-coordinate, each of the slices is located with respect to the reference origin, so that there are no cumulative errors. Accordingly, each slice may be positioned with an accuracy of, for example, 0.5 millimeters. In a typical example, the slices may have 2 inch diameters, with the reconstruction display having a one millimeter resolution, i.e., a 50 pixel by 50 pixel matrix due to the use of partial scanning. This dimension of slice may be obtained with the source of radiation and array of detectors extending only about 10 degrees above the surfáce of the operating table, with respect to the Z axis reference.

While reference is made to the movement of the scanning system, for scanning the different slices, it is of course apparent, that alternatively the patient may be moved with respect to the scanning system.

The slices, as above discussed, have been indicated to be 3 millimeters thick. This parameter is of course determined by the scanning system itself. It is preferred, however, that the centers of these slices be 2.5 millimeters apart, in order to provide a desired overlap between the slices.

In the scanning system employed in accordance with the invention, scanning speed is not essential, but the real time interaction between the scanning system and the probe system are of significant importance. In conventional scanning algorithms, reconstruction of the images provides information relating to the tissue properties, but does not definitively locate anatomical structures. In the use of probes, in accordance with the invention, it is necessary for the surgeon to identify anatomical positions, and it is for this reason that the delta μ algorithm must be employed, this algorithm defining the boundary conditions of the anatomical structure with sufficient accuracy for operation procedures.

The concept of partial scanning is concerned with the fact that only a portion of a given volume scanned is considered, in the reconstruction algorithm. Thus, referring to Fig. 5, it is assumed that the cross-sectional outline of the patient's head is defined by the line 40. In brain surgery, it is of course not necessary to obtain complete information throughout the section. Consequently, data is only considered with respect to obstruction of radiation passing through a circular area 41, having a radius r_s.

The heavy line 42 represents the x-ray beam and its position is identified by the polar coordinates ξ, ψ in the frame of reference whose origin is chosen at the center of the circle, as indicated in Figure 5. If $\beta(\xi, \psi)$ is the value of the attenuation suffered by the x-ray beam through the body, in partial scanning β is measured for all values of the angular coordinate ψ and for values of ξ equal to or less than r_s.

Referring now to the enlarged view of area 41 in Fig. 6, and assuming a polar frame of coordinates r, θ in the image plane, at each point P(r, θ) one derives from the measurements of β a weighted average $<\mu>$ of the linear attenuation coefficient

$$<\mu> = \frac{1}{4\pi r_1} \int_0^{\pi} \sum_{j=-\infty}^{+\infty} \Gamma_j \beta[r\cos(\psi-\theta) + j r_1, \psi] d\psi \qquad \text{I}$$

where r_1 is the computational sampling interval and coefficients Γ_j define the convolution kernel. In Equation (I) the missing values of β for $|\xi| > r_s$ are assumed to be constant for each value of ψ and equal to the last measured value at $|\xi| = r_s$. Thus in Equation (I) one assumes the continuity of β across the circle of radius r_s.

The apparent local value μ_a of the linear attenuation coefficient in the image plane depends upon the optics of the x-ray system and is a suitable average of the true local value of the attenuation coefficient over the beam cross section. The image reconstruction algorithm is based on the relationship between $<\mu>$ and μ_a:

$$<\mu> = \int_0^{2\pi} d\phi \int_0^{\infty} \mu_a(s, \alpha)\, \omega(\rho) \rho d\rho \qquad \text{II}$$

where $\omega(\rho)$ is the weighting function and:

$$\begin{cases} s = [r^2 + \rho^2 + 2r\rho\cos(\phi-\theta)]^{1/2} \\ \frac{1}{s}\sin(\phi-\theta) = \frac{1}{\rho}\sin(\alpha-\theta) \end{cases} \qquad \text{III}$$

ρ, ϕ being the polar coordinates relative to the reconstruction point P as indicated in Figure 6. The weighting function selected for the image reconstructions is a Gaussian distribution

$$\omega(\rho) = \frac{1}{r_1^2 \lambda^2} e^{-\left(\frac{\rho}{r_1 \lambda}\right)^2} \qquad \text{IV}$$

where λ is an arbitrary coefficient. Then the value of $<\mu>$ is essentially equal to the average value of μ_a within a circle of radius λr_1.

The convolution multipliers Γ_j are related to ω by the equations:

$$\frac{1}{2}\Gamma_0 + \theta_{1,|j|}\Gamma_1 + 2\theta_{2,|j|-1}\Gamma_2 + \dots + |j|\,\theta_{|j|,1}\Gamma_{|j|} = 2\pi \int_{|j|r_1}^{(|j|+1)r_1} \omega(\rho)\, \rho\, d\rho \qquad \text{V}$$

where

$$\theta_{h,k} = \frac{1}{h}\left[\sqrt{(h+k)^2-h^2} - \sqrt{(h+k-1)^2-h^2}\right] \qquad \text{VI}$$

and by virtue of the value of the weighting function given by Equation IV the right hand side of Equation V becomes

$$2\pi\int_{|j|}^{(|j|+1)r_1}\omega(\rho)\rho\, d\rho = e^{-\frac{j^2}{\lambda^2}} - e^{-\frac{(|j|+1)^2}{\lambda^2}} \qquad \text{VII}$$

A listing of the numerical values of Γ_j is given in Table I for several values of the parameter λ. The asymptotic value of Γ_j for $|j| >> \lambda$ is independent of λ and is equal to

$$\Gamma_j = -\frac{2}{\pi}\,\frac{1}{j^2} \qquad \text{VIII}$$

Assume now that one takes the difference $\Delta\mu$ between the values of $<\mu>$ computed at two different values λ_1, λ_2 of the parameter λ. Assume also $\lambda_2 > \lambda_1$ and a value of λ_1 of the order of unity. In the limit of $\lambda_2 >> 1$, such that $\lambda_2 r_1$ becomes larger than the dimensions of the body section, the only difference between the $\Delta\mu$ image and the image of $<\mu>$ reconstructed at $\lambda = \lambda_1$ is an arbitrary offset of the linear attenuation coefficient. Conversely, if one selects a value of λ_2 close to λ_1 and a small value of r_1, the $\Delta\mu$ image becomes the difference between the local value of μ_a and the average of μ_a within the circle of radius $\lambda_2 r_1$. Assume for instance $\lambda_2 = 2\lambda_1$ and a value of r_1 small compared to the dimensions of the body organs. In the limit of $r_1 \rightarrow 0$ the local value of $\Delta\mu$ yields:

$$\lim_{r_1 \rightarrow 0} \frac{\Delta\mu}{r_1^2} = -\frac{3}{4}\left\langle\frac{\partial^2\mu_a}{\partial\rho^2}\right\rangle_P \qquad \text{IX}$$

where the average of the second derivative at point P is computed over the total range 2π of the angular coordinate ϕ. By virtue of Equation IX regions of either uniform values of μ_a or uniform gradients of μ_a, yield zero $\Delta\mu$ values. Thus non zero values of $\Delta\mu$ are confined to the proximity of interfaces between regions of different values of μ as illustrated in Figure 7, which corresponds to the ideal case of a plane interface between two uniform regions. According to Equation IX the $\Delta\mu$ image reduces to two strips of positive and negative values separated by a line located at the interface between the two regions. The width of the positive and negative strips depends primarily upon μ_a and r_1 and consequently the spatial resolution of the $\Delta\mu$ image increases by increasing both the scanner spatial resolution and decreasing the sampling interval r_1. The magnitude of the change of $\Delta\mu$ across the interface depends upon the orientation of the interface relative to the scanning plane and increases with the difference between the values of μ across the interface itself. These considerations apply to anatomical structures as long as the local radius of curvature of the interface between body organs is sufficiently larger than r_1. Thus in the limit IX of the $\Delta\mu$ image, the outline of the body organs is given by the equation:

$$\Delta\mu = 0 \qquad \text{X}$$

The $\Delta\mu$ values are obtained from the attenuation values β by means of an equation identical to I where Γ_j are substituted by the new coefficients.

$$\Delta\Gamma_j = \Gamma_j(\lambda_1) - \Gamma_j(\lambda_2) \qquad \text{XI}$$

Because Equation VIII is independent of λ, the j^{-2} terms cancel out in the asymptotic expansion of $\Delta\Gamma_j$ for $|j| >> \lambda_2$. Asymptotically $\Delta\Gamma_j$ decreases rapidly with j according to the equation

$$(\Delta\Gamma_j)\ |j| >> \lambda_2 = \frac{K_1(\lambda_1, \lambda_2)}{j^4} \qquad \text{XII}$$

where $K(\lambda_1, \lambda_2)$ is a numerical constant equal to

$$K_1(\lambda_1, \lambda_2) \sim \frac{3}{\pi}\,(\lambda_2^2 - \lambda_1^2) \qquad \text{XIII}$$

A listing of $\Delta\Gamma_j$ values is presented in Table II for several combinations of values of λ_1 and λ_2. The rapid decrease of $\Delta\Gamma_j$ given by Equation XII makes it possible to reduce the radius r_s of the scanning circle to a fraction of the body dimensions without serious image distortions caused by the lack of measurements of β outside of the scanning circle.

TABLE I - Γ_j

J	.250	.500	1.00	2.00	4.00	10.00
0	.200000E+01	.196337E+01	.126424E+01	.442398E+00	.121173E+00	.199003E-01
1	-.577350E+00	-.556201E+00	-.163134E+00	.109536E+00	.577497E-01	.111488E-01
2	-.164130E+00	-.166309E+00	-.194570E+00	-.352457E-01	.380649E-01	.110394E-01
3	-.738420E 01	-.742578E-01	-.841560E-01	-.775770E-01	.129448E-01	.100671E-01
4	-.413549E-01	-.414827E-01	-.443852E-01	-.575726E-01	-.722496E-02	.865788E-02
5	-.263065E-01	-.263575E-01	-.274887E-01	-.347911E-01	-.183476E-01	.699149E-02
6	-.181722E-01	-.181963E-01	-.187244E-01	-.219224E-01	-.213030E-01	.520595E-02
7	-.132949E-01	-.133077E-01	-.135862E-01	-.151109E-01	-.193324E-01	.342184E-02
8	-.101451E-01	-.101525E-01	-.103130E-01	-.111357E-01	-.155668E-01	.174130E-02
9	-.799477E-02	-.799934E-02	-.809827E-02	-.858510E-02	-.118946E-01	.243563E-03
10	-.646205E-02	-.646503E-02	-.652929E-02	-.683713E-02	-.901663E-02	-.101796E-02
11	-.533133E-02	-.533335E-02	-.537689E-02	-.558159E-02	-.696186E-02	-.201603E-02
12	-.447342E-02	-.447484E-02	-.450539E-02	-.464702E-02	-.553060E-02	-.274725E-02
13	-.380715E-02	-.380817E-02	-.383023E-02	-.393146E-02	-.451774E-02	-.322775E-02
14	-.327940E-02	-.328016E-02	-.329649E-02	-.337081E-02	-.377651E-02	-.348773E-02
15	-.285428E-02	-.285485E-02	-.286720E-02	-.292303E-02	-.321459E-02	-.356570E-02
16	-.250679E-02	-.250724E-02	-.251674E-02	-.255952E-02	-.277564E-02	-.350326E-02
17	-.221913E-02	-.221948E-02	-.222692E-02	-.226025E-02	-.242448E-02	-.334073E-02
18	-.197831E-02	-.197858E-02	-.198449E-02	-.201085E-02	-.213822E-02	-.311418E-02
19	-.177467E-02	-.177489E-02	-.177964E-02	-.180077E-02	-.190126E-02	-.285355E-02
20	-.160094E-02	-.160112E-02	-.160498E-02	-.162212E-02	-.170256E-02	-.258206E-02
21	-.145154E-02	-.145169E-02	-.145486E-02	-.146891E-02	-.153413E-02	-.231632E-02
22	-.132212E-02	-.132224E-02	-.132487E-02	-.133650E-02	-.138998E-02	-.206715E-02
23	-.120928E-02	-.120938E-02	-.121158E-02	-.122128E-02	-.126558E-02	-.184064E-02
24	-.111029E-02	-.111038E-02	-.111223E-02	-.112039E-02	-.115741E-02	-.163929E-02
25	-.102298E-02	-.102306E-02	-.102463E-02	-.103155E-02	-.106273E-02	-.146313E-02
26	-.945586E-03	-.945649E-03	-.946990E-02	-.952892E-03	-.979364E-03	-.131063E-02
27	-.876654E-03	-.876708E-03	-.877861E-02	-.882926E-03	-.905546E-03	-.117939E-02
28	-.814996E-03	-.815042E-03	-.816038E-02	-.820411E-03	-.839859E-03	-.106671E-02
29	-.759623E-03	-.759663E-03	-.760528E-02	-.764323E-03	-.781139E-03	-.969870E-03
30	-.709709E-03	-.709744E-03	-.710498E-02	-.713808E-03	-.728426E-03	-.886378E-03

TABLE II - $\Delta\Gamma_j$

J	1-2	1-5	1-10	2-4	2-10	2-20
0	.82184E+00	.11858E+01	.12443E+01	.32122E+00	.42250E+00	.43740E+00
1	-.27267E+00	-.20322E+00	-.17428E+00	.51786E-01	.98387E-01	.10667E+00
2	-.15932E+00	-.22646E+00	-.20561E+00	-.73311E-01	-.46285E-01	-.38226E-01
3	-.65790E-02	-.10311E+00	-.94223E-01	-.90522E-01	-.87644E-01	-.80531E-01
4	.13187E-01	-.50299E-01	-.53043E-01	-.50348E-01	-.66230E-01	-.60442E-01
5	.78024E-02	-.23067E-01	-.34480E-01	-.16444E-01	-.41783E-01	-.37539E-01
6	.31989E-02	-.78649E-02	-.23930E-01	-.61940E-03	-.27128E-01	-.24520E-01
7	.15247E-02	.23700E-05	-.17008E-01	.42215E-02	-.18533E-01	-.17534E-01
8	.82270E-03	.32979E-02	-.12054E-01	.44311E-02	-.12877E-01	-.13366E-01
9	.48683E-03	.40250E-02	-.83458E-02	.33095E-02	-.88287E-02	-.10606E-01
10	.30784E-03	.35684E-02	-.55113E-02	.21795E-02	-.58192E-02	-.86390E-02
11	.20469E-03	.27536E-02	-.33609E-02	.13803E-02	-.35656E-02	-.71568E-02
12	.14163E-03	.19791E-02	-.17581E-02	.88358E-03	-.18998E-02	-.59923E-02
13	.10123E-03	.13790E-02	-.60249E-03	.58628E-03	-.70371E-03	-.50470E-02
14	.74324E-04	.95771E-03	.19124E-03	.40570E-03	.11691E-03	-.42601E-02
15	.55832E-04	.67532E-03	.69851E-03	.29156E-03	.64267E-03	-.35928E-02
16	.42772E-04	.48810E-03	.98651E-03	.21612E-03	.94374E-03	-.30192E-02
17	.33330E-04	.36246E-03	.11138E-02	.16423E-03	.10805E-03	-.25215E-02
18	.26363E-04	.27602E-03	.11297E-02	.12737E-03	.11033E-03	-.20873E-02
19	.21131E-04	.21478E-03	.10739E-02	.10049E-03	.10528E-03	-.17076E-02
20	.17137E-04	.17018E-03	.97708E-03	.80444E-04	.95994E-03	-.13755E-02
21	.14047E-04	.13690E-03	.86148E-03	.65226E-04	.84741E-03	-.10857E-02
22	.11624E-04	.11156E-03	.74228E-03	.53484E-04	.73065E-03	-.83400E-03
23	.97027E-05	.91943E-04	.62906E-03	.44297E-04	.61936E-03	-.61658E-03
24	.81633E-05	.76523E-04	.52706E-03	.37019E-04	.51890E-03	-.43024E-03
25	.69179E-05	.64252E-04	.43851E-03	.31187E-04	.43159E-03	-.27204E-03
26	.59017E-05	.54376E-04	.36364E-03	.26472E-04	.35774E-03	-.13925E-03
27	.50656E-05	.46349E-04	.30153E-03	.22620E-04	.29647E-03	-.29305E-04
28	.43727E-05	.39765E-04	.25067E-03	.19448E-04	.24630E-03	.60226E-04
29	.37945E-05	.34320E-04	.20934E-03	.16817E-04	.20555E-03	.13165E-04
30	.33089E-05	.29785E-04	.17588E-03	.14618E-04	.17257E-03	.18717E-04

Figs. 8 and 9 illustrate, in simplified form, a technique whereby the method and apparatus of the invention may be advantageously employed in surgical procedures. In this arrangement, an operating table 50 is provided, the table 50 being movable, for example, by having wheels 51 on its legs. In addition, a scanning system 52 for computerized tomography, may also be mounted to be movable, for example, on wheels 53. Of course provisions may be made for stabilizing each of these devices, in use, so that it cannot move. Since the scanner 52 is employed for partial scanning only, it is not necessary that the scanning portion of this device extend in a complete circle. Thus, the opening 54 of the circle is positioned so that the table 50 may be received therein, as illustrated in the figures. This permits the positioning of the patient, illustrated by the reference numeral 55 in Fig. 9, to be readily moved into and away from the tomographic apparatus. Since, in accordance with the invention, it is essential to main-

tain the frames of reference of the scanner and the probe assembly 56 rigid, the probe assembly may be rigidly coupled to the scanner as illustrated. In addition, since it is necessary to have absolutely no movement between the patient and the probe during a surgical procedure, the probe assembly 56 may be adapted to be rigidly held to the table, for example, by means of bolts 57 or the like.

With the arrangement of the type illustrated in Figs. 8 and 9, it is apparent that the scanning apparatus may be removed from the vicinity of the table if necessary, for example, in an emergency, but also that the scanning apparatus and probe assembly is readily placed into position when necessary for the surgical procedures, etc.

It is of course apparent that the illustrations of Figs. 8 and 9 are simplified, and employed to show an example of the type by which the method and apparatus of the invention may be employed.

Referring now to Fig. 10 therein is illustrated, in simplified form, a probe assembly which may be employed in accoradnce with the invention, enabling the accurate positioning of the probe at any determined point. For example, the probe assembly may be comprised of a base 60 having an upright column 61 with a vertical slot 62 therein. The slot has a vertically extending rack, and an arm 63 has a projection extending into this slot. A suitable pinion gear is provided in the assembly, to enable vertical movement of the arm 62, by means of a control knob 64. This control consequently enables positioning the probe in the Y-coordinate direction. The arm 63 carries a rider 65 that is movable therealong. The arm 63 has a rack 66 engageable with a pinion (not shown) rotatable by a knob 67 on the rider 65, thereby enabling movement of the probe in the X-coordinate direction. A further arm 68 is movable in the rider 65, transversely of the arm 63. This arm 68 has a rack 69 engaging a pinion coupled to the knob 70, thereby enabling movement of the probe in the Z-coordinate direction.

A horizontal arc 71 is affixed to the arm 68, and a rider 72 is movable on the arc 71. For this purpose, the arc 71 may have a rack 73 engageable with a pinion affixed to the knob 74, thereby enabling movement of the probe to define an angle of the probe with respect to the vertical central plane of the scan. The rider 72 carries a further arc 75 extending vertically therefrom, this arc 75 carrying a rider 76. The arc 75 has a rack 77 engageable with a pinion on a knob 78 on the rider, thereby enabling movement of the probe to define the angle thereof to the above-mentioned vertical plane. A further arm 79 is movable in the rider 76 transversely of the arc 75, the arm 79 having a rack 80 engageable with the pinion on a knob 81 in the rider, thereby enabling control of the depth of penetration of a probe, illustrated in simple form by the reference numeral 82 on the end of the arm 79.

It is of course apparent that the arrangement shown in Fig. 10 is illustrative only, and other techniques may alternatively be employed for positioning the probe accurately in its frame of reference. As further illustrated in Fig. 10, the various arms of the assembly may have suitable markings, to be able to control the coordinates and angles accurately. Alternatively, of course, the device may be arranged to automatically provide output signals corresponding to such parameters, and may further be automatically driven by the computer through the use of motor drives and shaft angle encoders for feedback.

Upon completion of the scanning sequence and image reconstructions, the process of identifying the pertinent landmarks and computing the trajectory of the probe may begin. In order to do so, it is necessary to relate the translational and rotational controls of the stereotactic guide with the coordinates of the landmarks which are measured in the frame of reference of the scanner (See Fig. 12).

A rectangular frame of coordinates x, y, z fixed with respect to the scanner is selected with the origin O on the axis of rotation of the scanner yoke and the axis z perpendicular to the scanning plane. The scanning plane is chosen at:

$$z = 0$$

and axes x, y are oriented in the horizontal and vertical directions respectively.

A spherical frame of reference r, θ, ϕ is chosen fixed with respect to the stereotactic guide. The origin O′ of this second frame is chosen at the position of the tip of the probe which corresponds to the zero setting of the probe penetration control. The position of a point T in this frame of reference is identified by its distance r from O′, the angle θ between line O′ T and a vertical axis parallel to y, and the angle ϕ between a vertical plane passing through O′ T and a horizontal axis parallel to z.

Assume that x'_1, y'_1, z'_1 denotes the settings of the three-translational controls of the stereotactic guide and x_0, y_0, z_0, is the coordinates of O′ in the frame of reference x, y, z when the stereotactic guide controls are set at

$$x'_1 = y'_1 = z'_1 = r = 0$$

Obviously the values of x_0, y_0, z_0, are known as part of the initial calibration phase of the system. Once the head is locked in the chosen position and a burr hole is made in the skull, the first step of the surgical procedure involves the positioning of the tip of the probe on the cortical surface at the center of the burr hole. This is done by adjusting the controls in the x′, y′ and z′ directions with the radial penetration control set at r = 0. Thus the position of the entrance point in the scanner frame of reference is determined by the known values x_0, y_0, z_0 and x'_1, y'_1, z'_1.

The axial position of the head relative to the scanner is changed by means of the indexing control which moves the platofrm supporting the stereotactic guide and the head holder in a direction perpendicular to the scanning plane. The scanning sequence is then performed by scanning at predetermined constant intervals z_s of the axial position z_n.

The position of a target point T in the frame of

reference x, y, z is identified by its coordinates x_T, y_T in the corresponding image plane and by the position of the image plane

$$z_n = nz_s$$

where the number n corresponds to the scan which contains T.

From the measured values of the coordinates of O' and T the probe is oriented in the direction of the line O'T by adjusting the angular controls of the stereotactic guide to the values of θ and ϕ:

$$\cos\theta = \frac{y_o+y'-y_T}{\sqrt{(x_o+x'-x_T)^2 + (y_o+y'-y_T)^2 + (z_o+z'-nz_s)^2}}$$

$$\sin\phi = \frac{x\ +x'-x_t}{\sqrt{(x_o+x'-x_T)^2 + (z_o+z'-nz_s)^2}}$$

and the penetration depth of the probe is given by

$$r = \sqrt{(x_o+x'-x_T)^2 + (y_o+y'-y_T)^2 + (z_o+z'-nz_s)^2}$$

The simplest possible situation is one where the target point is identifiable in the images, in which case x_T, y_T, nz_s are measured directly. It is then a straightforward procedure to compute the values of r, θ, ϕ and to reach the target point with the tip of the probe.

In a more general situation however, the target point may not be visible in the images and its position has to be determined in relation to landmarks within the partial scanning volume which are clearly identifiable in the image planes. In this case the procedure involves first the identification of the anatomy by means of the original images reconstructed parallel to the scanning plane and images reconstructed at specific orientations relative to the scanning plane to provide the three dimensional visualization of the anatomical structures under scrutiny. Once the landmarks are identified, the original images provide their coordinates and the knowledge of the anatomy permits the surgeon to determine the position of the target point. Then the above Equations provide again the guidance of the surgical procedure.

During the scanning procedure, and in subsequent procedures, it is of course absolutely necessary to maintain the frames of reference of the probe and scanner rigid with respect to one another, and it is of course equally as important to insure that the patient be held at a rigid position with respect to the frames of reference. The general holding procedure illustrated in Fig. 1 may not be capable of holding the patient sufficiently rigid, for example, for brain operations. In order to insure such rigidity, in accordance with a further feature of the invention as illustrated in Fig. 11, a hollow plug 90 is provided for insertion in the hole 91 of the skull 92. The plug 90 may be annular, and has a lip 93 adapted to engage the outer surface of the skull as illustrated. The plug 90 is adjustably affixed to a framework illustrated generally by the reference numeral 94, the frame having arms 95 or the like adapted to be rigidly affixed, for example by bolting, to the table or other rigid frame of reference. Three fastening points are preferred, for this purpose, in order to insure rigidity of the assembly. A further adjustable arm 96 of the framework has a holding member 97 on its end adapted to be received in the mouth 98 of a patient, to engage the roof 99 of the mouth. The adjustability of the arms in this arrangement enables the head to be clamped in the framework firmly, so that it cannot move with respect to the probe illustrated generally by the reference numeral 100. It is of course apparent that the illustrated arrangement is an example only, and that other structures of this type may alternatively be employed. The probe element may be initially held in the center of the plug, for example, by means of a frangible web 101, the probe being adapted to be releasably connected to the adjustable support therefore following insertion of the plug in the head. The plug may also be releasably coupled to the framework to simplify the assembly of the structure. As a consequence, the arrangement illustrated in Fig. 11 insures that there will be no movement of the patient with respect to the frames of reference of the scanner and probe, thereby insuring complete accuracy in the use of the probe.

In one embodiment of the invention, the computerized tomographic scanning system was comprised of a modified Tomoscan 200, a translate-rotate body scanner manufactured by Philips Medical Systems, Inc., Shelton, Conn. In this modification, the data acquisition portion of the translation strobe length was reduced to 48 millimeters, thereby defining the diameter of tissue image in the scanning plane. It is of course apparent that this constitutes only one example of the invention, and other types of apparatus may be employed in accordance with the invention.

While the invention has been disclosed and described with reference to a limited number of embodiments, it will be apparent that variations and modifications may be made therein. It is therefore intended in the following claims to cover each such variation and modification as falls within the true spirit and scope of the invention.

CLAIMS

1. A stereotactic surgery system comprising probe means and a computerized tomographic scanning system, said scanning system comprising a display, and means for reconstructing images on said display using partial scanning procedures with an algorithm that provides the difference between the local values of the linear attenuation coefficient and average of these values within a circle centered at each reconstruction point, and further comprising means maintaining the frames of reference of said probe means and scanning system rigid with respect to one another.

2. The system of claim 1 wherein said scanning system includes means for scanning, reconstructing and displaying said images as a series of spaced images derived from spaced images derived from a

sequence of scans taken in an axial direction through a subject.

3. The system of claim 2 further including a storage means, said storage means storing a plurality of landmark locations, means to input a desired target point to said system, said system further including a computer for calculating the coordinate location of said target point from a fixed location in said probe means reference frame.

4. The system of claim 3 wherein said computer calculates transverse data from said spaced image data for displaying a transverse image representing an image section transverse to said spaced images.

5. The system of claim 4 wherein all of said images are displayed simultaneously on said display means, and wherein said means for inputting a desired target point includes a light pen, coupled to said display means.

6. A stereotatic surgery system comprising probe means and a computerized tomographic scanning system, said scanning system comprising a display, a means for reconstructing images on said display, means for maintaining the frames of reference of said probe means and said scanning system rigid with respect to one another, said probe means including a mounted probe assembly having a plurality of degrees of movement, and said scanning means including an upright assembly having a source and detector package adapted for relative rotation about a point and along a linear axis, said source and detector package arrangement constructed in an open configuration, thereby allowing rapid deployment of said scanning system into position with respect to a subject being scanned.

7. The system of claim 6 wherein said system includes a table adapted to support said subject, said table positionable within said open scanner configuration to place said subject in proximity with said scanning means and said probe means.

8. The system of claim 6 wherein said probe means includes a probe having three degrees of freedom, each individually calibratable by vernier adjustment and wherein said scanning means is rigidly coupled with respect to said probe means, so that said scanning means and said probe means share the same coordinate face.

9. The system of claim 8 wherein said system further comprises a computer, said computer receiving data corresponding to said images produced by each successive scan, means for inputing a location on an image to said computer, said computer calculating a trajectory from said probe means to said location, and means for providng said trajectory in the form of coordinates for said probe means.

10. The system of claim 6 further including a storage means, said storage means storing a plurality of landmark locations, means to input a desired target point to said system, said system further including a computer for calculating the coordinate location of said target point from a fixed location in said probe means reference frame.

11. The system of claim 10 wherein said computer calculates transverse data from said spaced image data for displaying a transverse image representing an image section transverse to said spaced images.

12. A stereotactic surgery system comprising probe means defining a first frame of reference, a computerized tomographic scanning system comprising a source of penetrating energy, a detector assembly for receiving said energy and producing scanning signals, said source and detector assembly defining a second frame of reference, a display device, and computer means for receiving said signals and reconstructing an image on said display device, and means rigidly coupling said first and second frames of reference.

13. The system of claim 12 wherein said scanning system is adapted for partial scanning, whereby image reconstruction on said display corresponds to only a defined part of an object being scanned.

14. The system of claim 12 wherein said probe means has a plurality of degrees of freedom and is reproducibly settable in each of said degrees of freedom, said source of penetrating energy and detector assembly being movable along a given axis with respect to a subject being scanned to enable production of scanning signals corresponding to a plurality of slices, said computer means reconstructing images of said slices on said display device, whereby parts of said images on said display device are definable in said second frame of reference.

15. The system of claim 12 wherein said computer means is programmed to reconstruct images according to an algorithm that gives non-zero values only in the proximity of interfaces between different values of linear attenuation coefficient of a subject being scanned.

22. The system of claim 12 wherein the coordinates of said first and second frames of reference are referenced to a common origin.

23. The surgery system of claim 12 wherein said scanning system is adapted to scan equally spaced apart parallel slices in a subject, and to partially scan a volume including said slices.

24. The system of claim 12 wherein said probe means is movable, with respect to a subject, in three orthogonal directions of a rectangular coordinate system of said first frame of reference, and is further movable along a line defined by a polar coordinate system in said first frame of reference.

25. A stereotactic surgery system comprising probe means defining a first frame of reference and having a probe displaceable in a definable manner in said first frame of reference, a computerized tomographic scanning system comprising a source of penetrating energy and a detector assembly for receiving said energy and producing scanning signals, said source and detector assembly defining a second frame of reference, said scanning system further comprising a display device and computer means for receiving said signals and reconstructing an image on said display device, whereby the coordinates of points on a display on said display device are determinable in said second frame of reference, said first and second frames of reference having a determinable spatial relationship whereby said probe may be accurately positioned at a point defined by coordinates of said first frame of reference.

26. The system of claim 24 in which the computer means comprises means for constructing images on said display device in accordance with an algorithm that provides distinctive values in the proximity of interfaces between regions of an object being scanned having different values of linear attenuation coefficient.

27. A stereotactic surgery system substantially as herein described with reference to and as illustrated in the accompanying drawings.

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